Anisotropic effects on constitutive model parameters of aluminum alloys

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14. ABSTRACT

Simulation of low velocity impact on structures or high velocity penetration in armor materials heavily rely on constitutive material models. Model constants are determined from tension compression or torsion stress-strain at low and high strain rates at different temperatures. These model constants are required input to computer codes (LS-DYNA, DYNA3D or SPH) to accurately simulate fragment impact on structural components made of high strength 7075-T651aluminum alloy. Johnson- Cook model constants determined for Al7075-T651 alloy bar material failed to simulate correctly the penetration into 1" thick Al-7075-T651plates. When simulation go well beyond minor parameter tweaking and experimental results show drastically different behavior it becomes important to determine constitutive parameters from the actual material used in impact/penetration experiments. To investigate anisotropic effects on the yield/flow stress of this alloy quasi-static and high strain rate tensile tests were performed on specimens fabricated in the longitudinal ?L?, transverse ?T?, and thickness ?TH? directions of 1" thick Al7075 Plate. While flow stress at a strain rate of ~1/s as well as ~1100/s in the thickness and transverse directions are lower than the longitudinal direction. The flow stress in the bar was comparable to flow stress in the longitudinal direction of the plate. Fracture strain data from notched tensile specimens fabricated in the L, T, and Thickness directions of 1" thick plate are used to derive fracture constants.

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ANISOTROPIC EFFECTS ON CONSTITURIVE MODEL PARAMETERS OF ALUMINUM ALLOYS

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Abstract. Simulation of low velocity impact on structures or high velocity penetration in armor materials heavily rely on constitutive material models. Model constants are determined from tension, compression or torsion stress-strain at low and high strain rates at different temperatures. These model constants are required input to computer codes (LS-DYNA, DYNA3D or SPH) to accurately simulate fragment impact on structural components made of high strength 7075-T651aluminum alloy. Johnson-Cook model constants determined for Al7075-T651 alloy bar material failed to simulate correctly the penetration into 1" thick Al-7075-T651plates. When simulation go well beyond minor parameter tweaking and experimental results show drastically different behavior it becomes important to determine constitutive parameters from the actual material used in impact/penetration experiments. To investigate anisotropic effects on the yield/flow stress of this alloy quasi-static and high strain rate tensile tests were performed on specimens fabricated in the longitudinal “L”, transverse “T”, and thickness “TH” directions of 1" thick Al7075 Plate. While flow stress at a strain rate of ~1/s as well as ~1100/s in the thickness and transverse directions are lower than the longitudinal direction. The flow stress in the bar was comparable to flow stress in the longitudinal direction of the plate. Fracture strain data from notched tensile specimens fabricated in the L, T, and Thickness directions of 1" thick plate are used to derive fracture constants.

Keywords: Aluminum, projectile impact simulation, strain rate sensitivity, Johnson-Cook, constitutive model.
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INTRODUCTION

Aluminum 7075 alloys are candidate materials for cold formable shapes that act as containment for ordnance applications. Over the last few years, a number of alloys have been characterized to determine their suitability for impact mitigation of different types of ordinance explosions. The studies involve numerical simulations of structures to impact scenarios. In order to simulate projectile (fragment) impact on structural components made of thick Al7075-T651 plates, accurate constitutive model constants determined from tests performed on test specimens fabricated from the actual material under investigated are required as input for computer codes (DYNA3D). Recent studies on a number of alloys (e.g., Mg-AZ31B-O) suggest that material response is highly anisotropic [1]. Yield and flow stress in rolling (L), transverse to rolling (T), and thickness (TH) directions is significantly different. The objective of the present research is to compare modeling parameters for thick plate with the published parameters derived from round bar stock material of Al7075-T651. The current focus is to study the property differences in the L, T, and TH directions at high strain rate and temperature and infer their influence in deriving constitutive model parameters.

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EXPERIMENTAL METHOD

Materials and Specimen Specifications

Tension specimens in the sub-size ASTM E8 configuration were fabricated in L, T, TH directions from 1-inch thick Al7075-T651 Plate. Sample dimensions from plates were identical to those prepared from bar stock, except in the thickness direction, since the plate thickness was smaller than the original sample length. This was achieved by maintaining the gage length and reducing the threaded section.

Quasi-Static Strain Rate Test Technique

Quasi-static (~1/s) tests were performed at ambient conditions on a MTS Servo hydraulic machine equipped with an 11 kip actuator. Load was measured with a load cell calibrated over an appropriate range. A slack adapter allowed the actuator to attain test speed before applying load to the specimen. Strain was measured using back-to-back strain gauges bonded on the specimen Post-yield strain was measured using a lightweight mechanical extensometer.

Tension split Hopkinson Bar Technique

The schematic of the Tension Split Hopkinson Bar at the University of Dayton Research Institute is shown in Fig. 1. The apparatus consists of a striker bar and two pressure bars, 0.5 in. (12.7 mm) in diameter and made of Inconel 718. The striker bar is launched in a compressed air gun. It strikes the incident bar end to end and produces a compressive stress pulse in incident bar. The tensile specimen is placed into the threaded holes in the two pressure bars. A collar is inserted around the specimen and the specimen is tightened in until the pressure bars are snug against the collar. The stress wave generated by the impact of the striker bar on incident bar is transmitted through the collar into the transmitter bar without affecting the specimen. It reflects back from the free end of the transmitting bar as a tensile wave and subjects the specimen to a tensile pulse. A part of the incident (tensile) pulse, ε_i, is transmitted through the specimen ε_t and the rest is reflected back through the incident bar ε_r.Incident, reflected, and transmitted are analyzed following the procedure described by Nicholas [2].

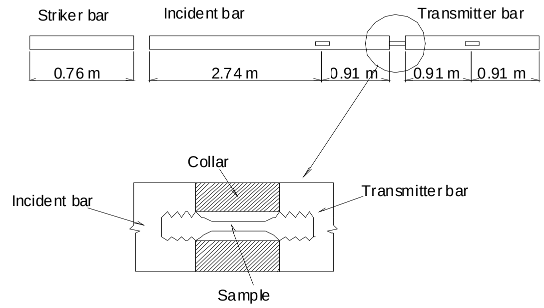

Figure 1. Schematic of the Tension Split Hopkinson Bar.

RESULTS AND DISCUSSION

Typical quasi-static tension stress-strain data for Al7075-T651 specimens fabricated from a 3/8" diameter bar stock and 1" thick plate at a strain rate of ~1/s are shown in Fig. 2. Since the yield stress for bar stock and plate specimens in “L”, “T”, and “TH” are similar, the constant “A” for Johnson-cook material strength model [3] for bar or plate is not expected to be significantly different.

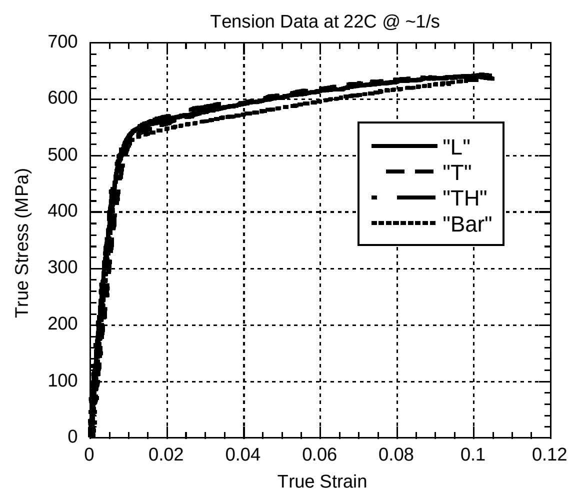

Figure 2. Tension data from 3/8" diameter bar stock and three directions from 1” thick plate.

High strain rate (~1000/s) tension data measured at ambient temperature in “L”, “T”, and “TH” orientation is shown in Fig. 3. Differences in the flow stress of “T”, and “TH” specimen compared to “L” are observed, but the difference in the failure strain is pronounced. This observation leads us to believe that the model constants “B”, “n” and “C” may need re-evaluation, but are beyond the scope of current work.

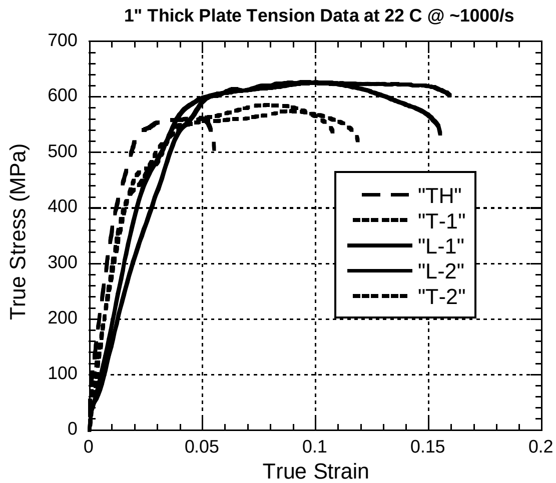

Figure 3. High strain rate data at 22° C.

High strain rate data on specimens in "L", "T", and "TH" orientation at 160° C and 250° C are shown in Figs. 4 and Fig. 5 respectively. The data show a similar trend as observed at room temperature, but is very pronounced. These differences reflect varying temperature constant in the three orientations and needed evaluation

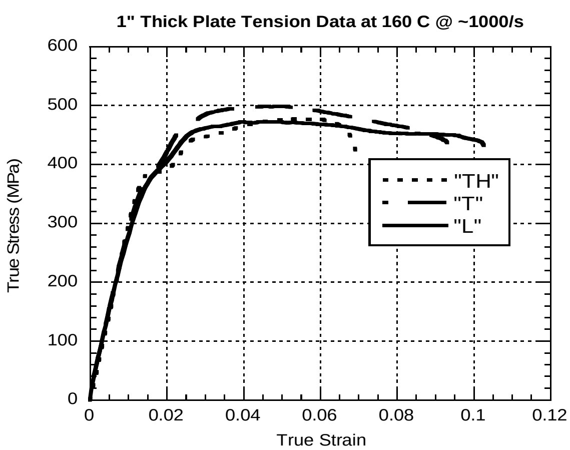

Figure 4. High strain rate data at 160° C.

The model constant "m", derived from the slope of normalized stress vs. homologous temperature, as plotted in Fig. 6 for three orientation reflects the deviation from model constant derived from bar stock. Variation of values from 1.23 to 1.71 represents the range of values in the strength modeling constant "m".

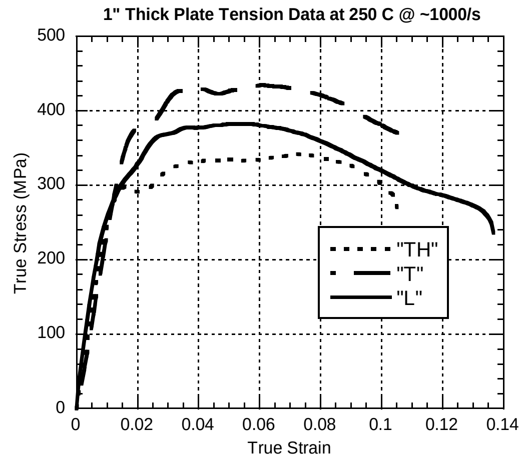

Figure 5. High strain rate data at 250° C.

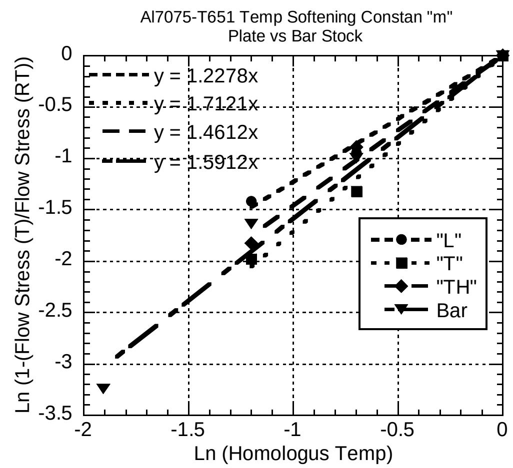

Figure 6. Normalized Flow stress vs. Temperature data.

Effect of Specimen orientation on J-C Fracture (Damage) Model Constants

Fracture model is Fracture model is defined as

$$\varepsilon_f = \left[D_1 + D_2 e^{D_3\sigma^*}\right]\left[1 + D_4 \ln\dot{\varepsilon}^*\right]\left[1 + D_5 T^*\right]$$

where ε_f is the equivalent plastic fracture strain, σ^* is the stress triaxility factor (STR), and D_1, D_2, D_3, D_4, and D_5 are fracture model constants [3]. Constants D_1, D_2, and D_3 were determined by performing room temperature tension tests at a strain rate of ~1/s on un-notched (smooth), ASTM E8 specimens, (STR = 1/3), and notched specimens (notch radii, 0.4-mm, 0.8-mm, 2.0-mm) to vary STR (= $1/3 + \ln(1 + a_o/2R_o)$), where a_o and R_o are the original specimen radius at the notch center and notch radius, respectively [4]. Equivalent fracture strain at failure, ε_f, is determined as

$$\varepsilon_f = \mathrm{Ln}\,(A_o/A_f)$$

where A_o and A_f are the specimen cross-section area before and after the test respectively. Specimen fracture areas were measured using traveling microscope. Data on ε_f and STR for the bar and plate specimens are plotted in Figs. 7 and Fig. 8 to determine constants D_1, D_2, and D_3 using Levenberg-Marquardt optimization method [5] from software iterative program on fracture model equation above.

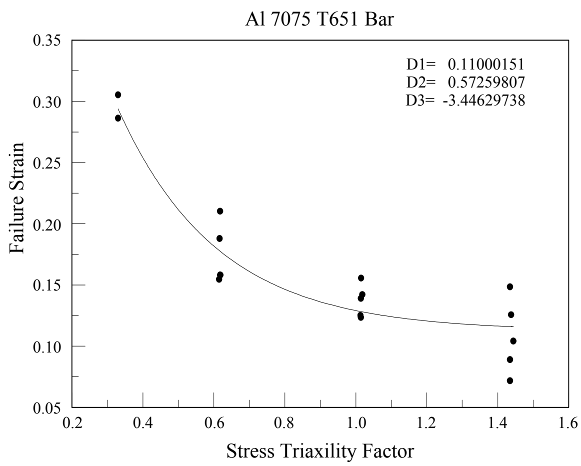

Figure 7. J-C Fracture Model Constants D_1, D_2, and D_3 for bar specimens of Al7075-T651.

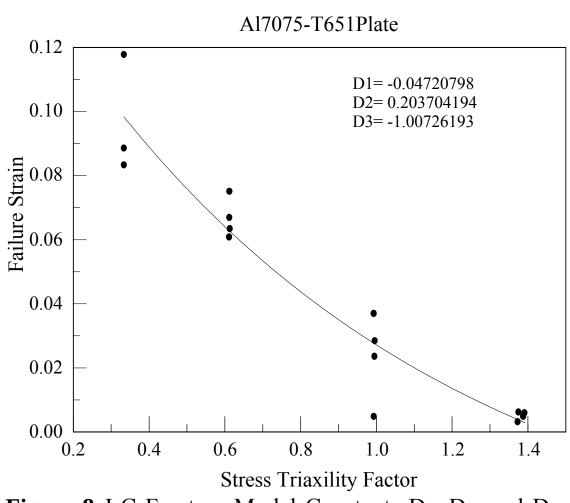

Figure 8 J-C Fracture Model Constants D_1, D_2, and D_3 for plate specimens of Al7075-T651.

Values of constants D1, D2, and D3 evaluated for bar and plate specimens are summarized in Table 1.

Table 1. J-C fracture model constants for Al7075-T651 bar and plate specimens.

Constant	Bar	Plate
D1	0.110	-0.047
D2	0.572	0.204
D3	-3.446	-1.007

CONCLUSIONS

(1) High strain rate as well as high temperature yield and flow stress ($\varepsilon = 0.5$) data in "L", "T", and "TH" orientations of 1" thick Al7075-T651 plate are significantly anisotropic.

(2) Observed anisotropy suggest that there are no unique values for constitutive (Johnson-Cook) model constants; rather a range of values which are optimized for simulating an impact event.

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